TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 692

SOME FUNDAMENTAL CONSIDERATIONS IN REGARD TO THE USE OF POWER IN LANDING AN AIRPLANE

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SUMMARY

This note is concerned with the effect of power on landing speed and apparent maximum lift coefficient. It is shown that when secondary effects are neglected, the maximum available increase in lift due to power is equal to the thrust being developed. If the increase in lift due to power is expressed in coefficient form, very high values may be shown under conditions which, on analysis, are found to be wholly impracticable in flight.

INTRODUCTION

It is an obvious and a well-known fact that the "landing speed" of an airplane depends on the amount of power being used and that the landing speed with power is lower than the stalling speed in a glide without power. There is no simple method of precise analysis that enables the calculation of the exact landing speed for any given airplane, but it is possible to obtain a very close approximation from consideration of the fundamental quantities involved.

In view of the current interest in the effect of power on landing speed, it has seemed desirable to indicate in a general way the factors involved and the physical limits to increasing lift by means of slipstream effects.

MOMENTUM REACTION

The product of mass by velocity, or MV, is known as momentum. Newton's Second Law of Motion states that the measure of a force is the rate of change in the momentum it produces. In the usual symbolic form, the second law is

$$F = M\ (V_2 - V_1)/t \qquad (1)$$

When the motion starts from rest $V_1 = 0$, so that

$$F\ t = M\ V \qquad (2)$$

Newton's Third Law of Motion states that action and reaction are equal and opposite. When a projectile is fired from a gun, the force acting on the projectile is accompanied by an equal and opposite force, or reaction, acting on the gun.

Wing lift and propeller thrust are reactions obtained by imparting momentum to the air. The airplane wing derives its lift by imparting downward momentum to the air upon which it acts. Lift and vertical momentum imparted in unit time must be equal and opposite in steady horizontal flight. Lift can be increased only by increasing the downward momentum. This means increasing the mass of air acted on, increasing the downward velocity, or increasing the product of the two. The mass of air influenced by the wing is very great, even under normal conditions. As shown in reference 1, the disturbance or downwash is perceptible about 20 chord lengths below the wing.

Thrust is obtained from the axial momentum imparted by the propeller to the slipstream. In an airplane, the slipstream constitutes an increment in momentum that may be employed to augment the normal wing lift. However, the actual increase in lift so obtained can never be greater than the thrust. An apparent additional increase can, of course, be obtained in an airplane having poor wing-root fillets or nacelle fairings that cause an early breakdown in the air flow in the absence of the slipstream. This condition is not present in a good design and it may be neglected in this discussion.

It must be emphasized that the foregoing analysis has been concerned with lift and thrust as forces - not as coefficients. It is possible to make use of coefficients under conditions to be indicated later.

EFFECT OF SLIPSTREAM ON LANDING SPEED

For equilibrium in horizontal flight, the normal lift on the wings L_W, plus the lift due to thrust L_T, must be equal to the weight W, or

$$L_W + L_T = W \tag{3}$$

The lift on the wings is given by

$$L_W = C_L\, q\, S \tag{4}$$

where $q = \frac{1}{2}\rho V^2$ and S is the wing area. The lift due to thrust is some function of the thrust T, or

$$L_T = f(T) = K\, T \tag{5}$$

Combining these equations,

$$C_L\, q\, S = W - K\, T \tag{6}$$

from which, at $C_{L_{max}}$, the landing speed V_L is

$$V_L = \sqrt{\frac{W - K\, T}{C_{L_{max}} \frac{1}{2}\rho\, S}} \tag{7}$$

The landing speed with power is given relative to the stalling speed without power by

$$\frac{V_L}{V_S} = \sqrt{\frac{W - KT}{W}} = \sqrt{1 - \frac{KT}{W}} \tag{8}$$

In the analysis of the preceding section, it was concluded that the lift due to thrust could never exceed the thrust except for the effect of the suppressed burble in the case of an initially defective wing fairing. K is numerically equal to the ratio of the increased lift to the thrust and therefore should normally be less than unity and rarely greater than unity.

This may be demonstrated by flight tests. Consider the data given in the table on page 8 of reference 2. The gross weight is stated on page 15 to be 1,550 pounds.

With flaps up the stalling speed was reduced from 46.8 miles per hour to 41.3 miles per hour by the use of power. From figure 11 of the same report, the power available at 41 miles per hour is t.hp. = 40, from which

$$T = \frac{375 \times 40}{41} = 366 \text{ lb.}$$

Hence the calculated landing speed with power, with $K = 1.0$ in equation (8), is

$$V_L = 46.8 \times \sqrt{1 - \frac{366}{1550}} = 40.9 \text{ m.p.h.}$$

which is very close to the observed value of 41.3. The indicated value of K is 0.94 in this case.

For the same airplane with flaps down, the use of power reduced the stalling speed from 41.3 miles per hour to 35.2 miles per hour. From figure 11 of reference 2, at 35 miles per hour, t.hp. = 37. Hence, the thrust was

$$T = \frac{375 \times 37}{35} = 397 \text{ lb.}$$

With $K = 1.0$ in equation (8), the calculated landing speed with power would be

$$V_L = 41.3 \sqrt{1 - \frac{397}{1550}} = 35.6 \text{ m.p.h.}$$

which is also in very close agreement with the observed value of 35.2 miles per hour. In this case the indicated value of K is 1.06.

THE EFFECT OF SLIPSTREAM ON APPARENT MAXIMUM LIFT COEFFICIENT

Since stalling speed varies inversely as $\sqrt{C_{L_{max}}}$, an equivalent $C_{L_{max}}$ may be obtained for the landing speed, V_L, using equation (8). Denoting the coefficient with power by C_{L_P}

$$C_{L_P} = \frac{C_{L_{max}}}{\left(1 - \frac{KT}{W}\right)} \tag{9}$$

If the lift due to thrust is 0.5W, then $C_{L_P} = 2C_{L_{max}}$. If $KT = W$, then $C_{L_P} = \infty$ and the airplane can maintain a vertical, hovering attitude.

It may be clearer to start from equation (3) written in a slightly modified form

$$L_P = L_W + L_T \tag{3a}$$

This equation simply states that the total lift with power equals the normal wing lift plus the increment due to the slipstream. If equation (3a) is divided through by qS

$$\frac{L_P}{qS} = \frac{L_W}{qS} + \frac{L_T}{qS} \tag{10}$$

All terms are lift coefficients and at $C_{L_{max}}$

$$C_{L_P} = C_{L_M} + \Delta C_{L_P} \tag{11}$$

where

$$\Delta C_{L_P} = \frac{L_T}{qS} \tag{12}$$

ΔC_{L_P} may have very high values when the product qS is small. Reducing qS does not affect $C_{L_{max}}$ but it does increase both ΔC_{L_P} and C_{L_P}.

This may be shown by assuming values of L_T/S and calculating ΔC_{L_P} as a function of the dynamic pressure q. Figure 1 indicates the type of the variation obtained.

GENERAL DISCUSSION

Since the actual lift increase due to power can never be greater than the thrust being developed, it follows that the total wing area in the slipstream is a secondary factor in the production of this lift. There is some dependence, however, of the angle for maximum lift on the relative intensity of the wing circulation (or downwash) and the slipstream. If any increase in lift is obtained from multiple propellers of the same total power, it must be due to the greater thrust being developed and not to the additional wing area in the slipstream.

A casual inspection of figure 1 might give the impression that enormous increases in $C_{L_{max}}$ can be obtained by the use of power. A careful study will show, however, that there is a fairly definite practical limit dictated by the thrust available. Figure 2 gives ΔC_{L_p} in terms of T/b.hp. and W/b.hp. The curves in this figure are obtained from equation (9) by assuming $K = 1.0$ and taking $T/W = (T/b.hp.)/(W/b.hp.)$, with $C_{L_{max}} = 2.00$. A normal value of T/b.hp. in the landing condition will rarely exceed 4.0, even if full power is used. It should also be noted that the handling properties of the airplane may restrict the amount of power that can be used in landing and, in particular, the power cannot be greater than that required in horizontal flight. In general, this last restriction operates very effectively to limit the percentage of power that can be used on an airplane having a low power loading. Consequently, large increases in $C_{L_{max}}$ are theoretically possible but highly impracticable.

CONCLUSIONS

1. The actual increase in lift due to the use of power can never be greater than the thrust being developed (except for airplanes having defective wing fairing.)

2. Flight tests indicate that the value of K in equations (5) and (8) is substantially unity, hence the momentum in the slipstream is completely absorbed in the downwash or wing momentum.

3. The landing speed with power may be calculated from the stalling speed without power by the use of equation (8), when the available or permissible thrust is known.

4. It is impossible to use in landing any more power than that required for horizontal flight at the landing speed since otherwise the airplane would climb.

Bureau of Aeronautics, Navy Department,
Washington, D. C., March 2, 1939.

REFERENCES

1. Jones, E. T.: A Full Scale Determination of the Angle of Downwash below an Aeroplane. R. & M. No. 1094, British A.R.C., 1927.

2. Reed, Warren D., and Clay, William C.: Full-Scale Wind-Tunnel and Flight Tests of a Fairchild 22 Airplane Equipped with External-Airfoil Flaps. T.N. No. 604, N.A.C.A., 1937.

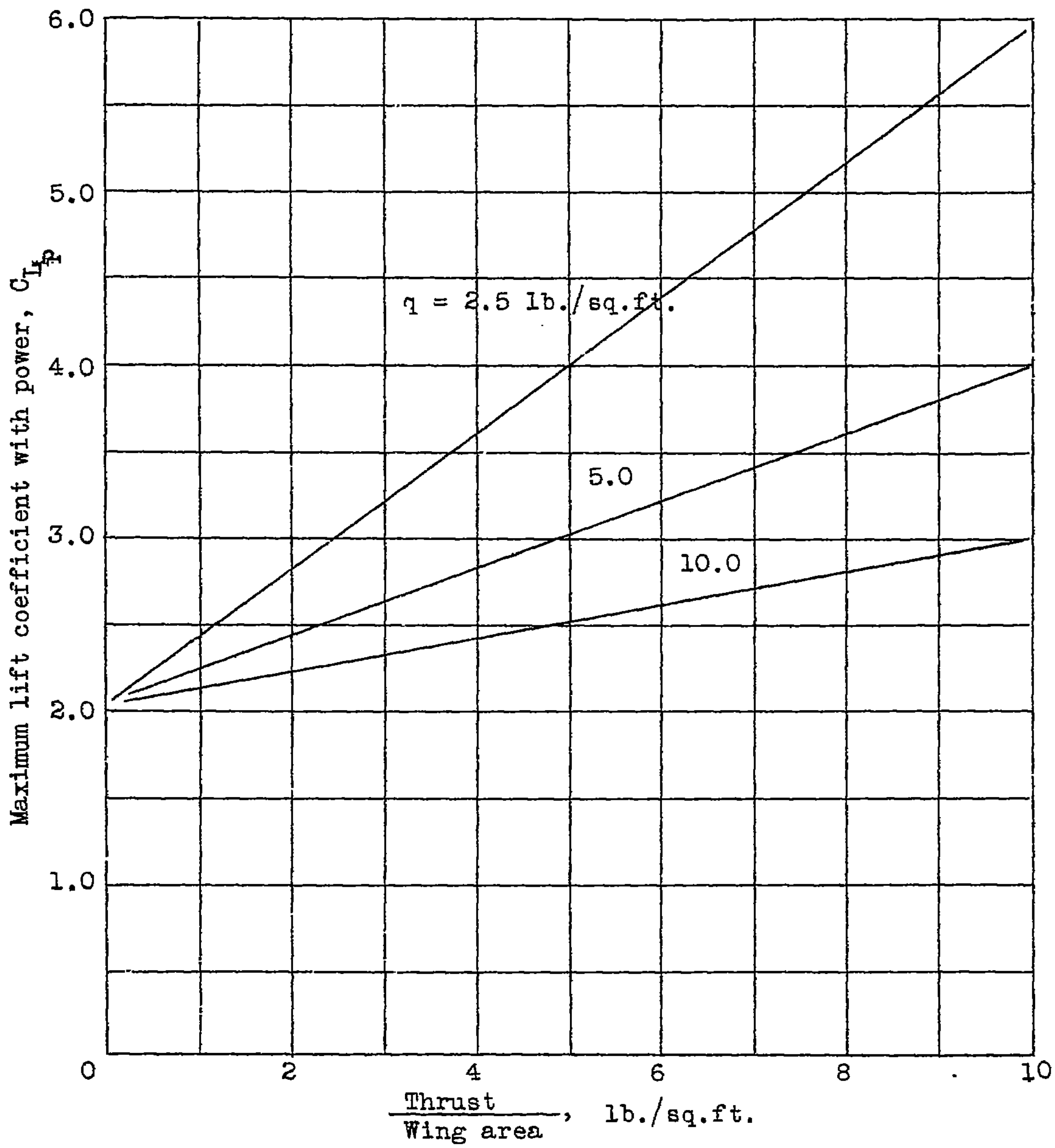

Figure 1.- Effect of power on apparent lift coefficient.

Basic wing $C_{L_{max}} = 2.0$

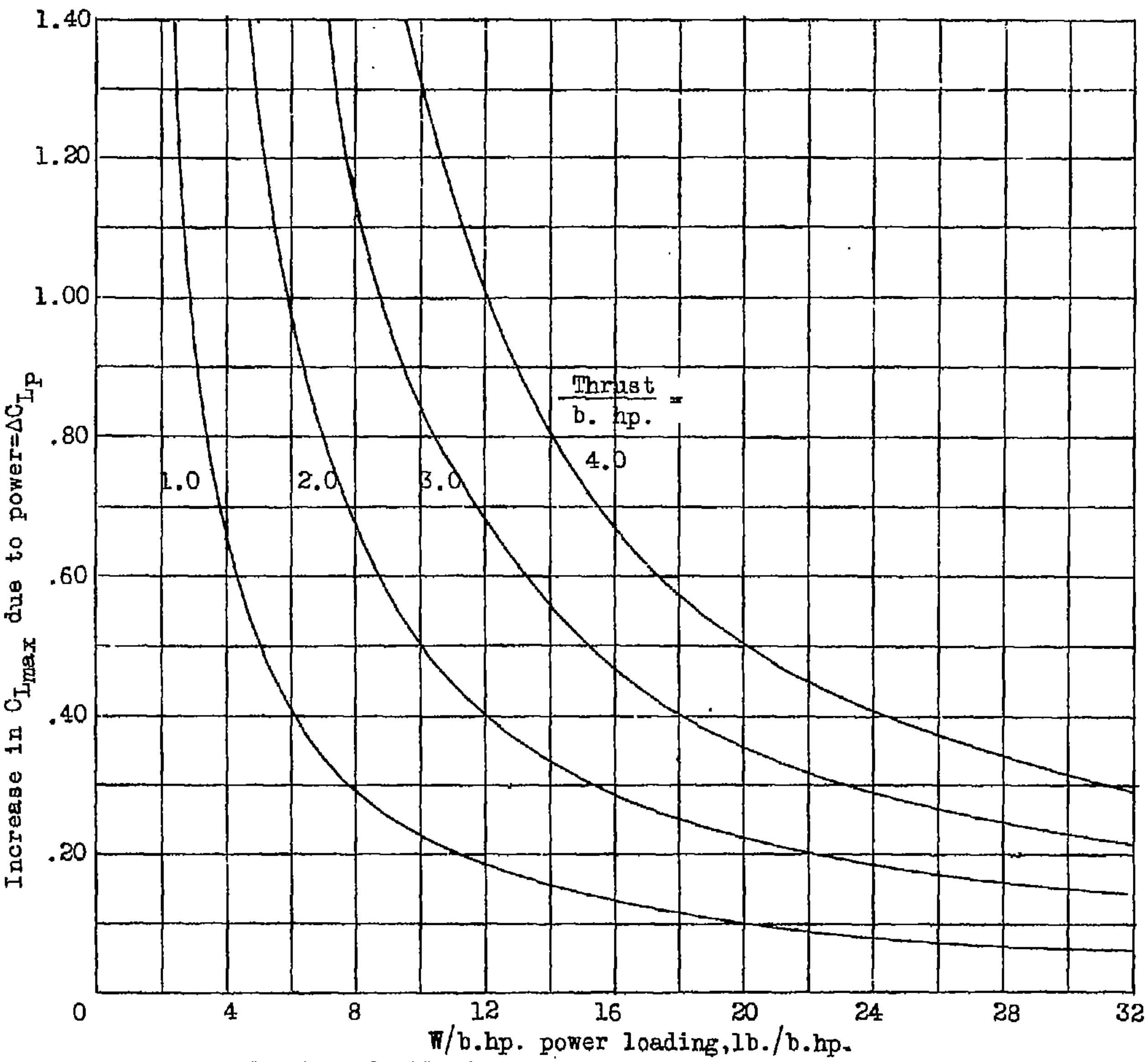

Figure 2. - Total available increase in $C_{L_{max}}$ due to power. $C_{L_{max}}$ = 2.00